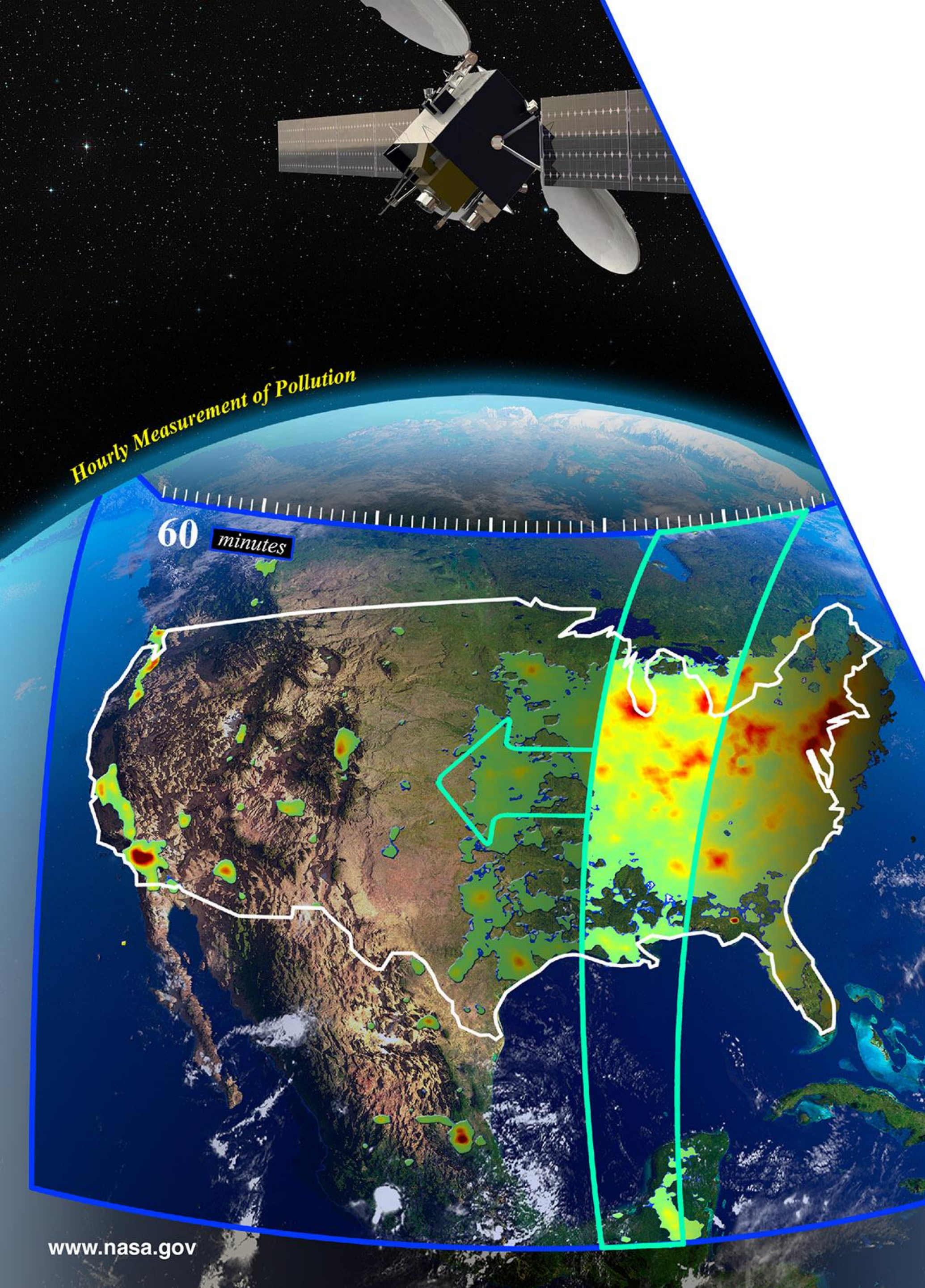


Tropospheric Emissions:
Monitoring of Pollution

Tropospheric Emissions: Monitoring of Pollution TEMPO

Chemical Weather R2O in SPoRT

Mike Newchurch
UAH

SPoRT Briefing

Ball Smithsonian NASA

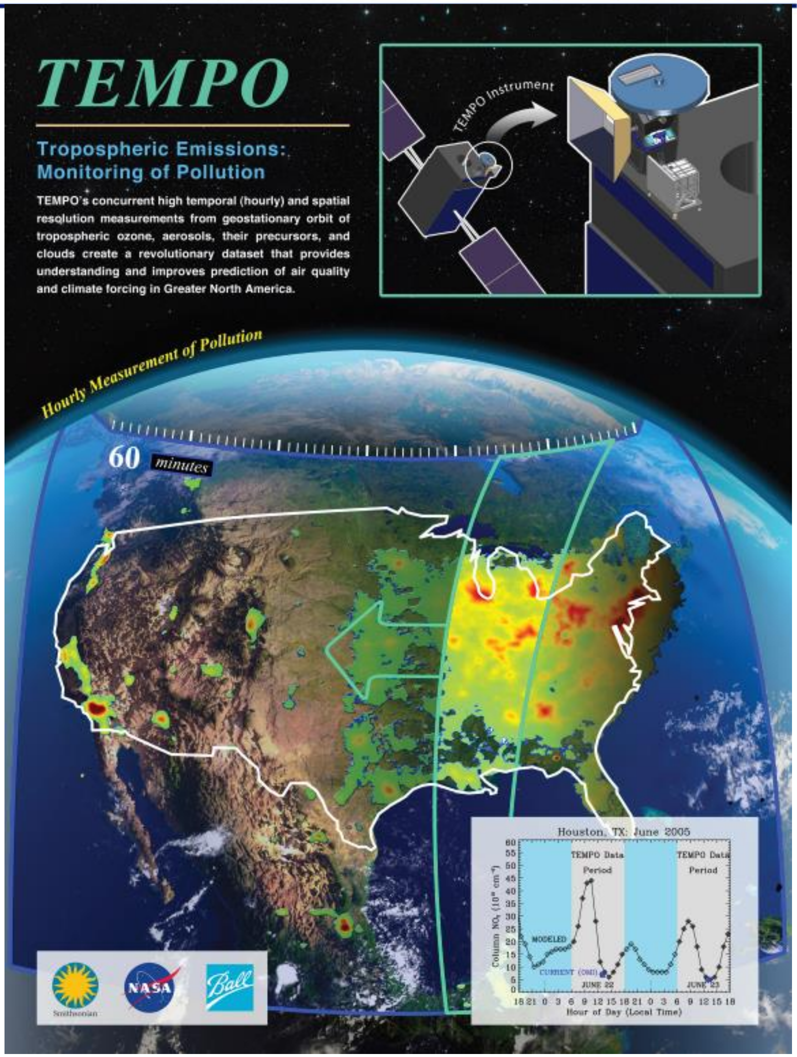
TEMPO

Abstract

Following very successful transitions of NASA physical-weather research to operations (R2O) in the NWS over the past decade, it may be time for SPoRT to consider R2O for chemical weather research. NASA has a long heritage in space-borne observation of air pollution (gases and aerosols) from LEO and is now on the verge of placing an instrument in GEO (2018 or later) to observe hourly changes in the chemical weather over CONUS. NASA also supports a significant research effort in global and regional modeling that includes data assimilation and OSSEs; however, little effort is currently being placed on transitioning this capability to operations in NOAA/NWS (or anywhere else). This description of the TEMPO mission and products is designed to spark a discussion of mutual interest in considering this new chemical weather observing and modeling capability as a viable candidate for SPoRT to adopt as one of its clients.

Hourly atmospheric pollution from geostationary Earth orbit

PI: Kelly Chance, Smithsonian Astrophysical Observatory
Instrument Development: Ball Aerospace
Project Management: NASA LaRC
Other Institutions: NASA GSFC, NOAA, EPA, NCAR, Harvard, UC Berkeley, St. Louis U, U Alabama Huntsville, U Nebraska, RT Solutions, Carr Astronautics
International collaboration: Korea, U.K., ESA, Canada, Mexico



Selected Nov. 2012 as NASA's first Earth Venture Instrument

- Instrument delivery May 2017
- NASA will arrange hosting on commercial geostationary communications satellite with launch expected NET 11/2018

Provides hourly daylight observations to capture rapidly varying emissions & chemistry important for air quality

- UV/visible grating spectrometer to measure key elements in tropospheric ozone and aerosol pollution
- Exploits extensive measurement heritage from LEO missions
- Distinguishes boundary layer from free tropospheric & stratospheric ozone

Aligned with Earth Science Decadal Survey recommendations

- Makes many of the GEO-CAPE atmosphere measurements
- Responds to the phased implementation recommendation of GEO-CAPE mission design team

North American component of an international constellation for air quality observations

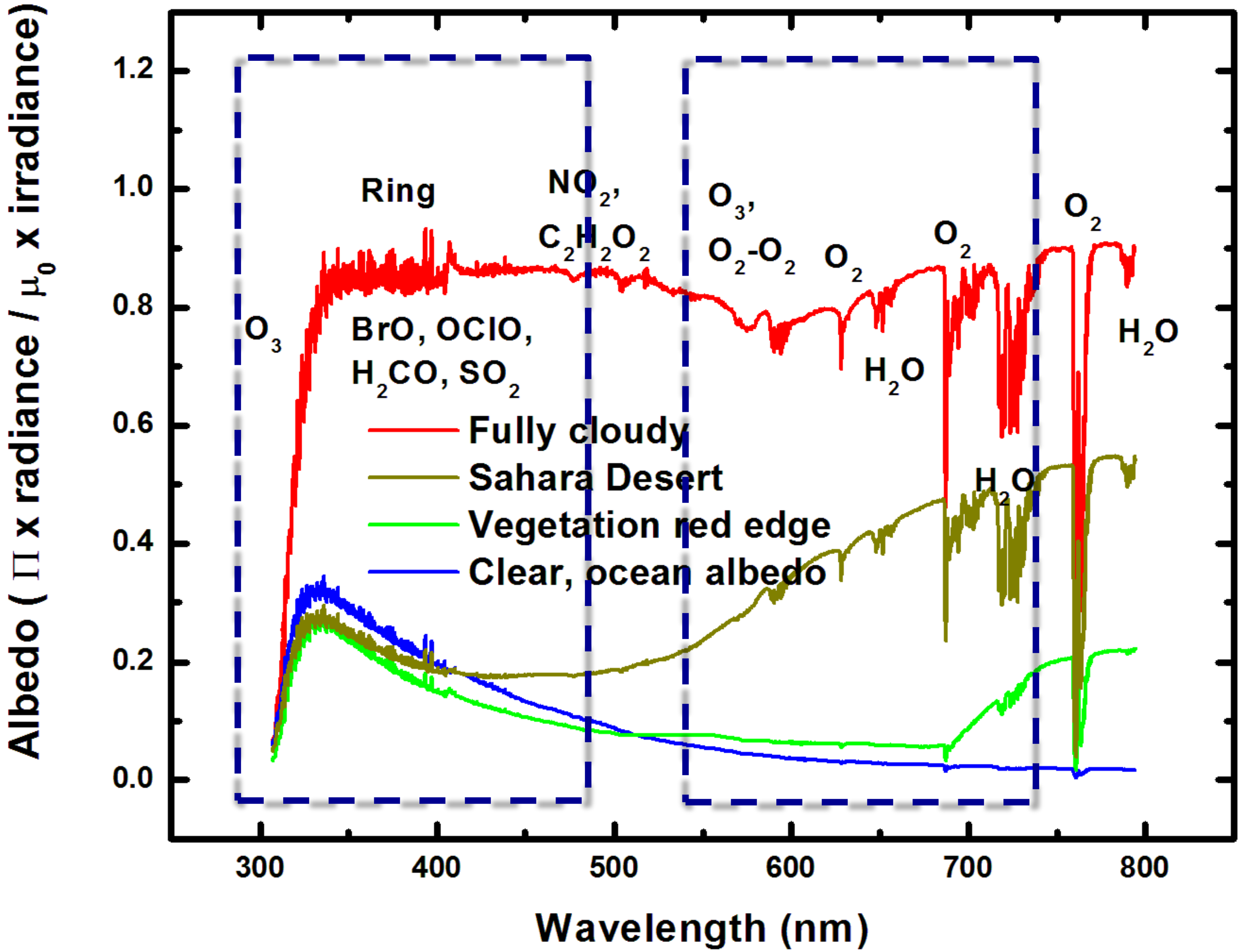
TEMPO science team

Team Member	Institution	Role	Responsibility
K. Chance	SAO	PI	Overall science development; **Level 1b, H_2CO, $C_2H_2O_2$**
X. Liu	SAO	Deputy PI	Science development, data processing; **O_3 profile, tropospheric O_3**
J. Al-Saadi	LaRC	Deputy PS	Project science development
J. Carr	Carr Astronautics	Co-I	**INR Modeling and algorithm**
M. Chin	GSFC	Co-I	Aerosol science
R. Cohen	U.C. Berkeley	Co-I	NO_2 validation, atmospheric chemistry modeling, process studies
D. Edwards	NCAR	Co-I	VOC science, synergy with carbon monoxide measurements
J. Fishman	St. Louis U.	Co-I	AQ impact on agriculture and the biosphere
D. Flittner	LaRC	Project Scientist	Overall project development; STM; instrument cal./char.
J. Herman	UMBC	Co-I	Validation (PANDORA measurements)
D. Jacob	Harvard	Co-I	Science requirements, atmospheric modeling, process studies
S. Janz	GSFC	Co-I	Instrument calibration and characterization
J. Joiner	GSFC	Co-I	**Cloud, total O_3, TOA shortwave flux research product**
N. Krotkov	GSFC	Co-I	**NO_2, SO_2, UVB**
M. Newchurch	U. Alabama Huntsville	Co-I	Validation (O_3 sondes, O_3 lidar)
R.B. Pierce	NOAA/NESDIS	Co-I	AQ modeling, data assimilation
R. Spurr	RT Solutions, Inc.	Co-I	**Radiative transfer modeling for algorithm development**
R. Suleiman	SAO	Co-I, Data Mgr.	Managing science data processing, **BrO, H_2O, and L3 products**
J. Szykman	EPA	Co-I	AIRNow AQI development, validation (PANDORA measurements)
O. Torres	GSFC	Co-I	**UV aerosol product, AI**
J. Wang	U. Nebraska	Co-I	Synergy w/GOES-R ABI, **aerosol research products**
J. Leitch	Ball Aerospace	Collaborator	Aircraft validation, instrument calibration and characterization
D. Neil	LaRC	Collaborator	GEO-CAPE mission design team member
R. Martin	Dalhousie U.	Collaborator	Atmospheric modeling, air mass factors, AQI development
Chris McLinden	Environment Canada	Collaborator	Canadian air quality coordination
Michel Grutter de la Mora	UNAM, Mexico	Collaborator	Mexican air quality coordination
Brian Kerridge	Rutherford Appleton Laboratory, UK	Collaborator	Ozone profiling studies, algorithm development
Paul Palmer	Edinburgh U., UK	Collaborator	Atmospheric modeling, process studies
J. Kim	Yonsei U.	Collaborators, Science Advisory Panel	Korean GEMS, CEOS constellation of GEO pollution monitoring
C.T. McElroy	York U. Canada		CSA PHEOS, CEOS constellation of GEO pollution monitoring
B. Veihelmann	ESA		ESA Sentinel-4, CEOS constellation of GEO pollution monitoring

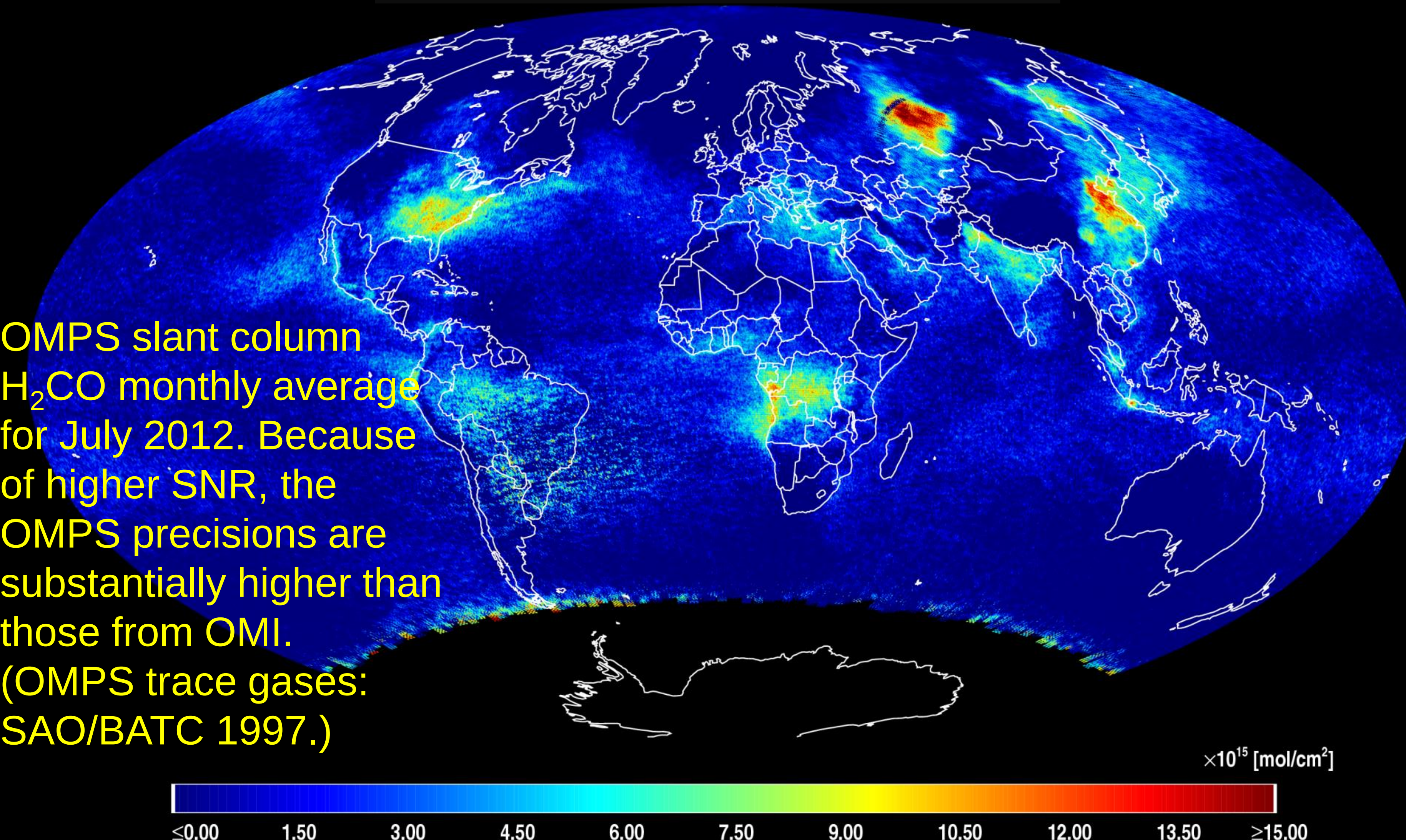
TEMPO instrument concept

- **Measurement technique**
  - Imaging grating spectrometer measuring solar backscattered Earth radiance
  - Spectral band & resolution: 290-490 + 540-740 nm @ 0.6 nm FWHM, 0.2 nm sampling
  - 2 2-D, 2k×1k, detectors image the full spectral range for each geospatial scene
- **Field of Regard (FOR) and duty cycle**
  - Mexico City/Yucatan Peninsula to the Canadian tar/oil sands, Atlantic to Pacific
  - Instrument slit aligned N/S and swept across the FOR in the E/W direction, producing a radiance map of Greater North America in one hour
- **Spatial resolution**
  - 2.1 km N/S × 4.7 km E/W native pixel resolution (9.8 km^2)
  - Co-add/cloud clear as needed for specific data products
- **Standard data products and sampling rates**
  - Most sampled hourly, including eXceL O_3 (troposphere, PBL) for selected areas
  - H_2CO, $C_2H_2O_2$, SO_2 sampled hourly (average results for ≥ 3/day if needed)
  - Nominal spatial resolution 8.4 km N/S × 4.7 km E/W at center of domain (can often measure 2.1 km N/S × 4.7 km E/W)
  - Measurement requirements met up to 50° for SO_2, 70° SZA for other products

Typical TEMPO-range spectra (from ESA GOME-1)



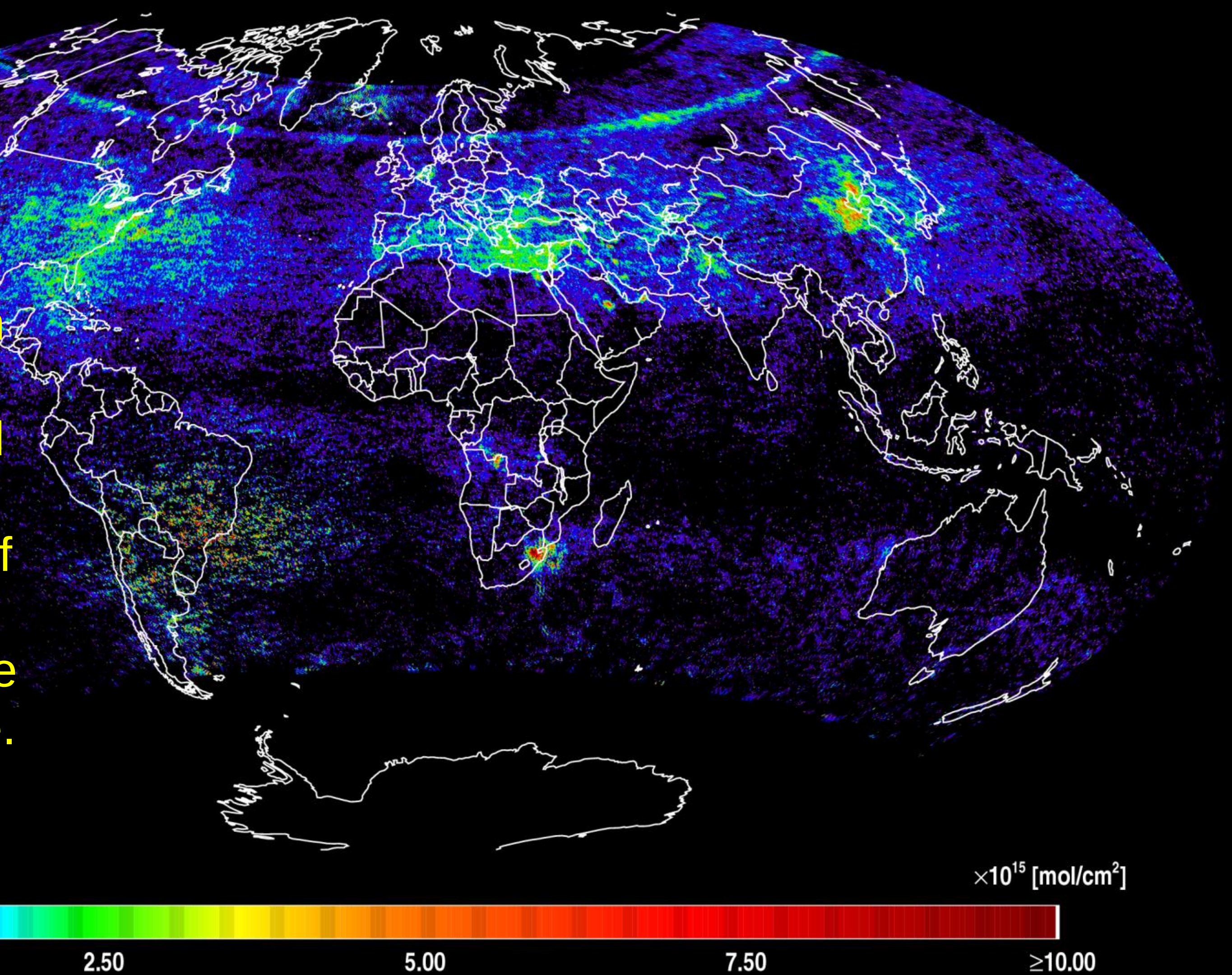
Algorithm testing: OMPS H_2CO



OMPS slant column H_2CO monthly average for July 2012. Because of higher SNR, the OMPS precisions are substantially higher than those from OMI. (OMPS trace gases: SAO/BATC 1997.)

Algorithm testing: OMPS NO_2

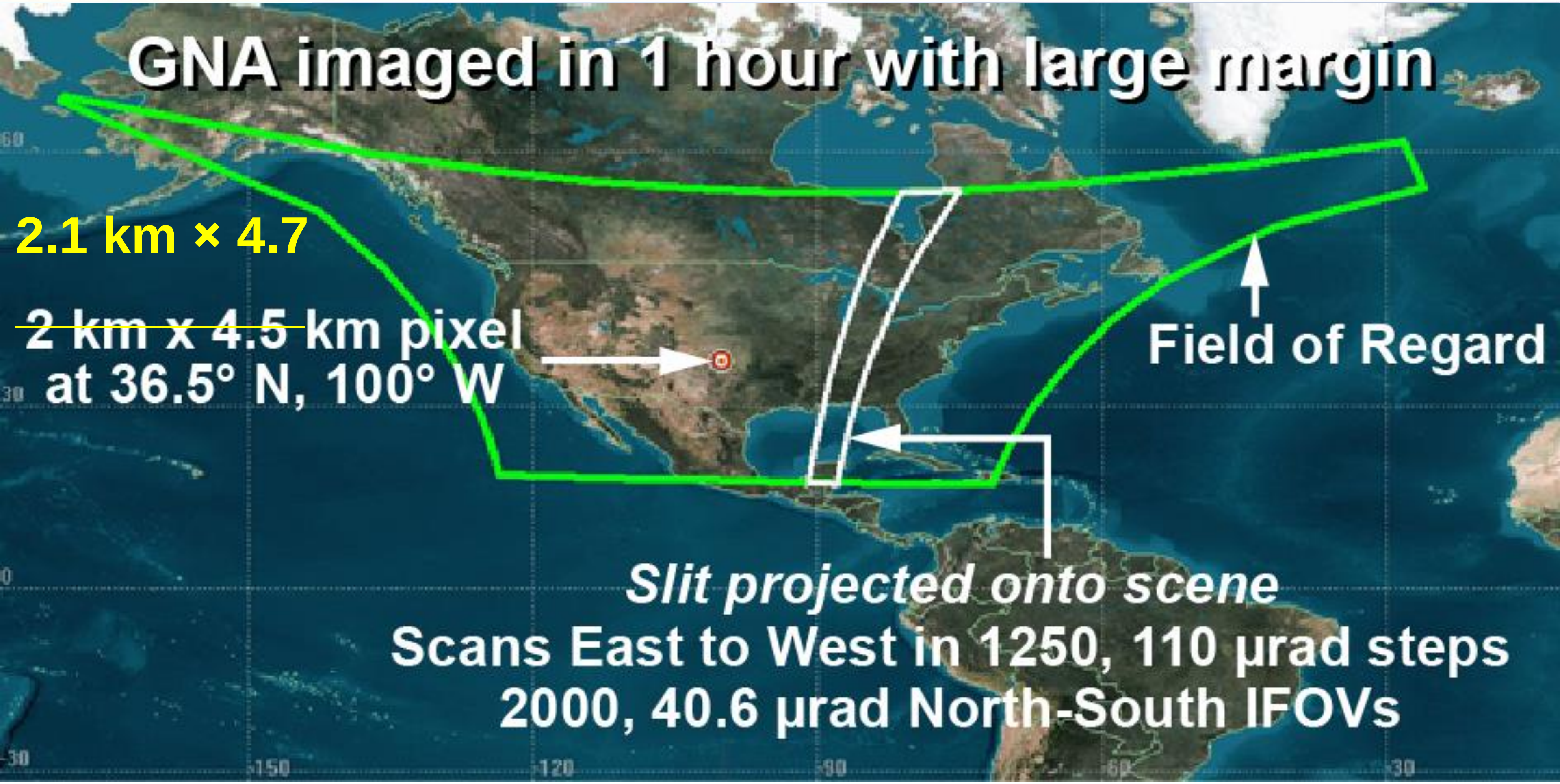
OMPS tropospheric slant column NO_2 for July 2-7, 2012. Much optimization remains to improve fitting and remove artifacts but the data are nearly of sufficient quality for scientific studies. The SAA is readily visible. (OMPS trace gases: SAO/BATC 1997.)



TEMPO mission concept

- **Geostationary orbit, operating on a commercial telecom satellite**
  - NASA will arrange launch and hosting services (per Earth Venture Instrument scope)
    - 80-115^{o} W acceptable latitude
    - Specifying satellite environment, accommodation
  - Hourly measurement and telemetry duty cycle for at least ≤70^{o} SZA
    - **Hope to measure up to 20 hours/day**
- **TEMPO is low risk with significant space heritage**
  - All proposed TEMPO measurements have been made from low Earth orbit satellite instruments to the required precisions
  - All TEMPO launch algorithms are implementations of currently operational algorithms
    - NASA TOMS-type O_3
    - SO_2, NO_2, H_2CO, $C_2H_2O_2$ from fitting with AMF-weighted cross sections
    - Absorbing Aerosol Index, UV aerosol, Rotational Raman scattering cloud
    - eXceL profile/tropospheric/PBL O_3 for selected geographic targets
- **Example higher-level products: Near-real-time pollution/AQ indices, UV index**
- **TEMPO research products will greatly extend science and applications**
  - **Example research products:** eXceL profile O_3 for broad regions; BrO from AMF-normalized cross sections; height-resolved SO_2; additional cloud/aerosol products; vegetation products

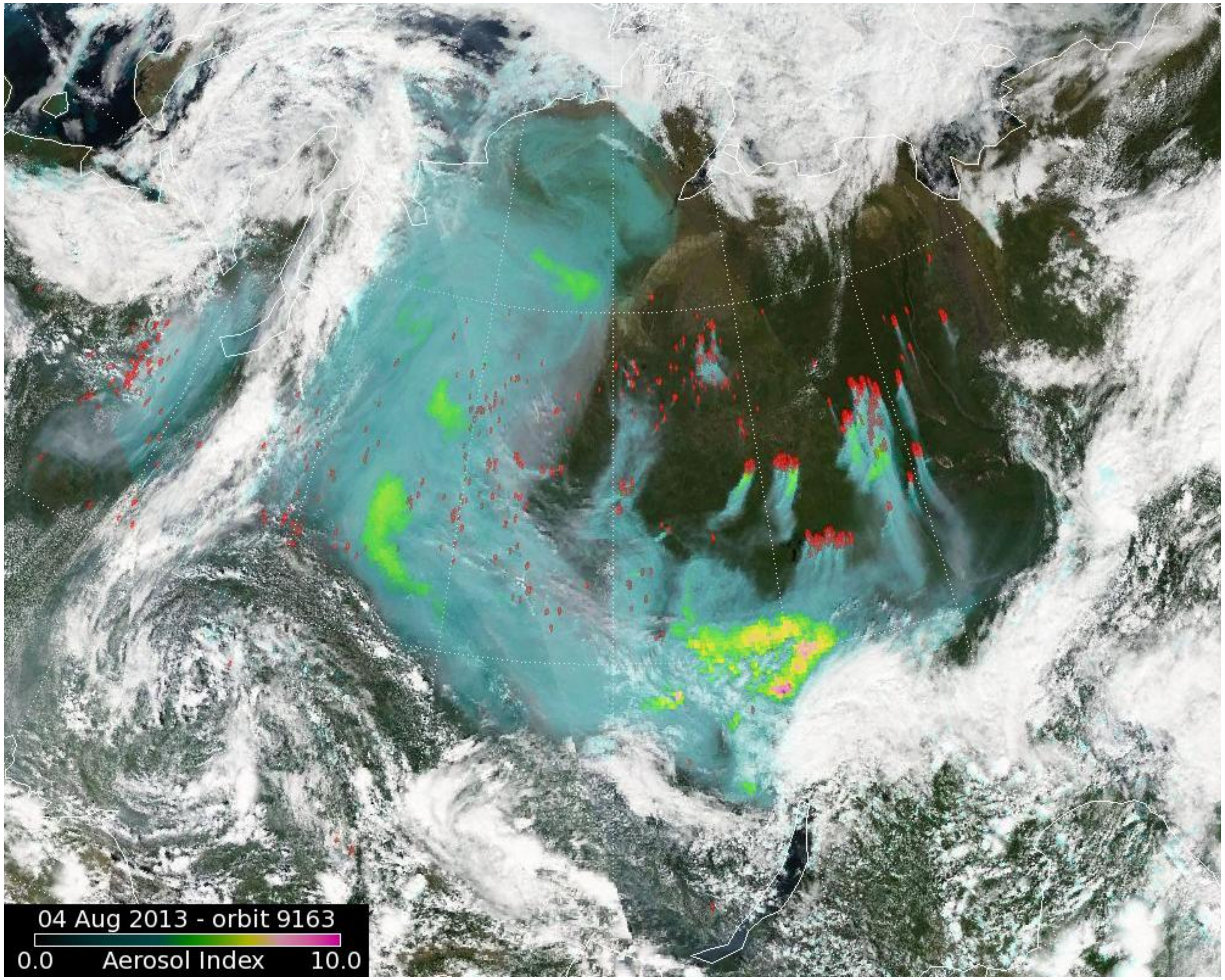
TEMPO footprint, ground sample distance and field of regard



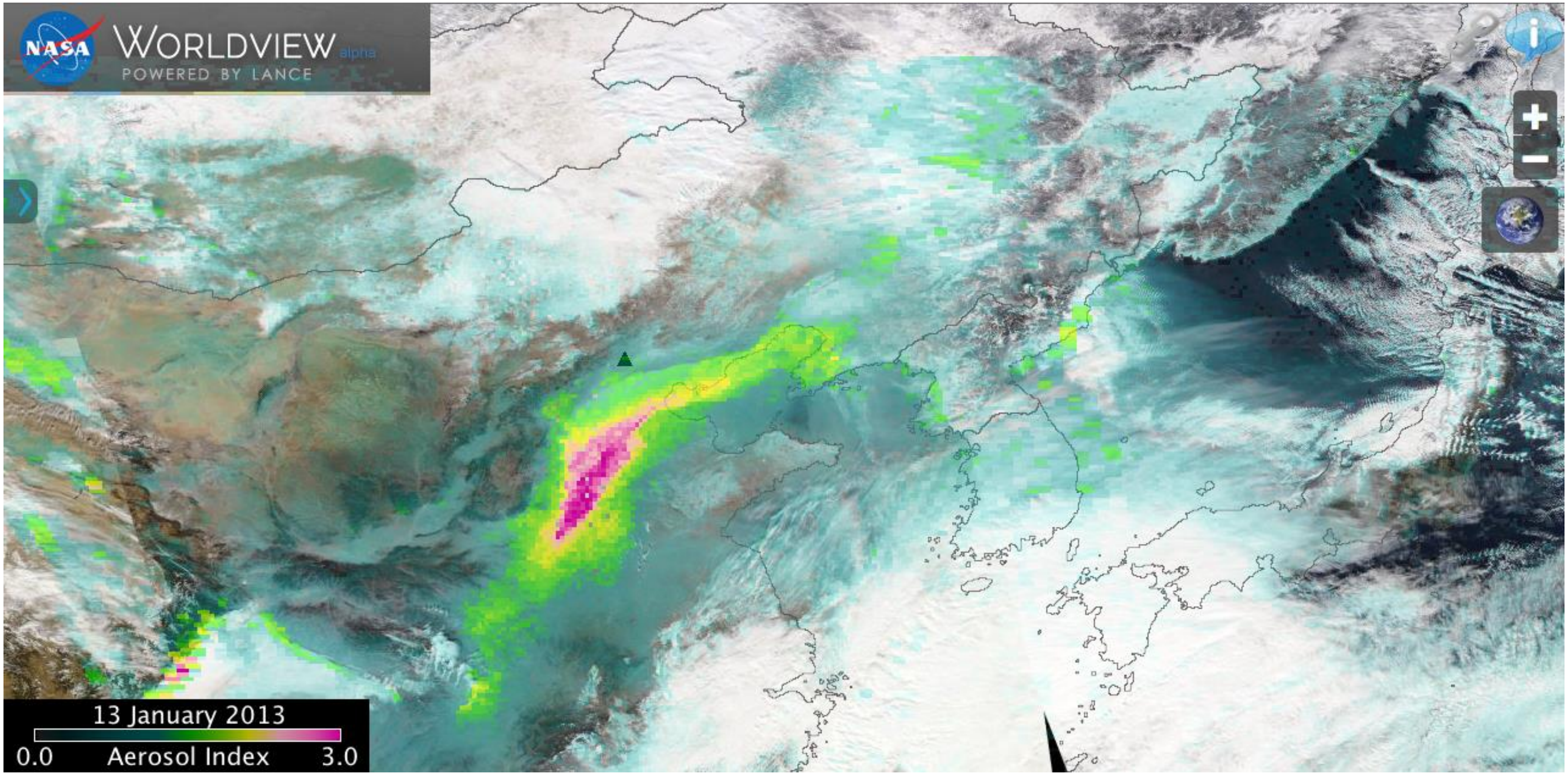
Each 2.1 km × 4.7 km pixel is a 2K element spectrum from 290-740 nm

GEO platform selected by NASA for viewing Greater North America

Smoke from Russian Fires (Aug 4, 2013)

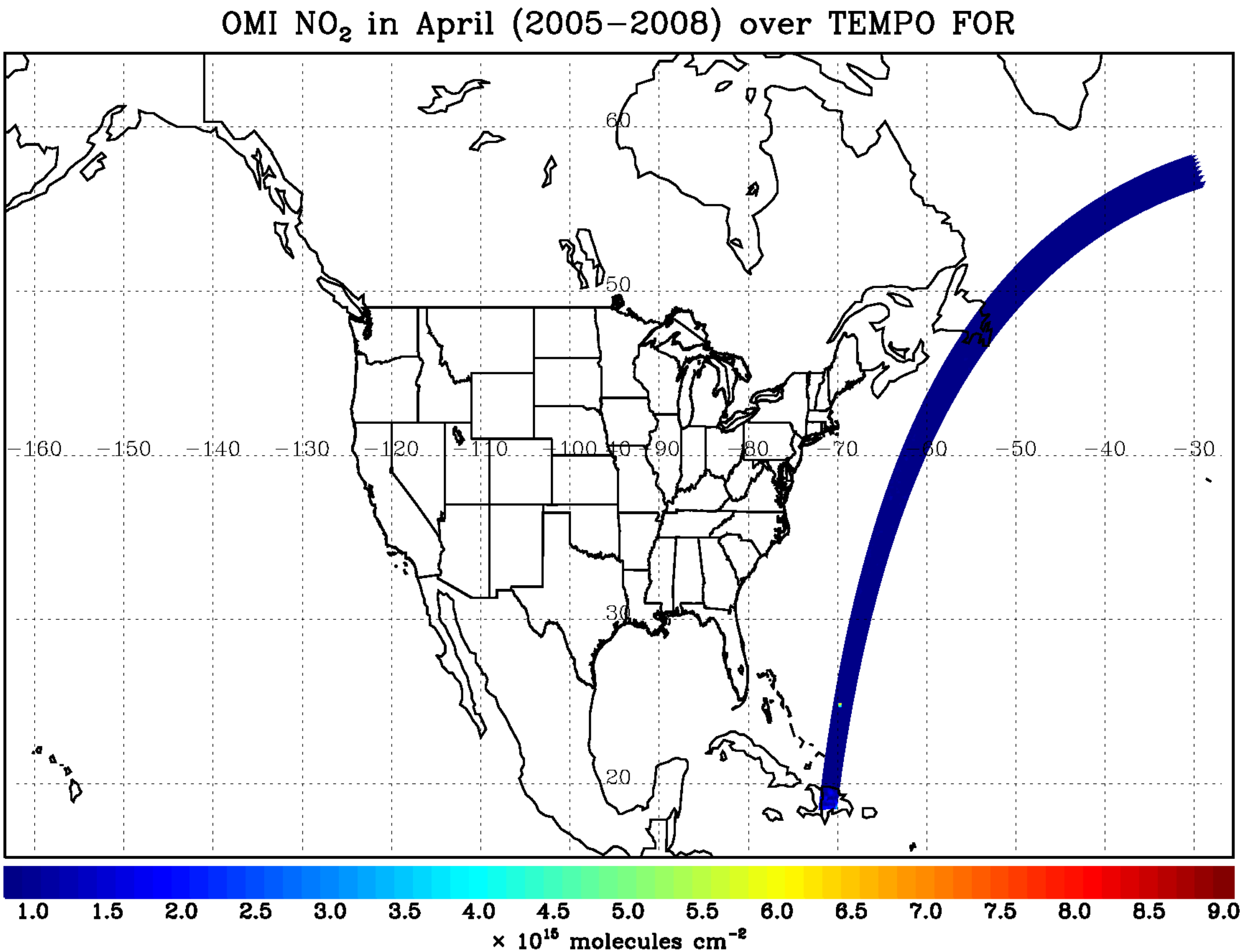


Air pollution over China



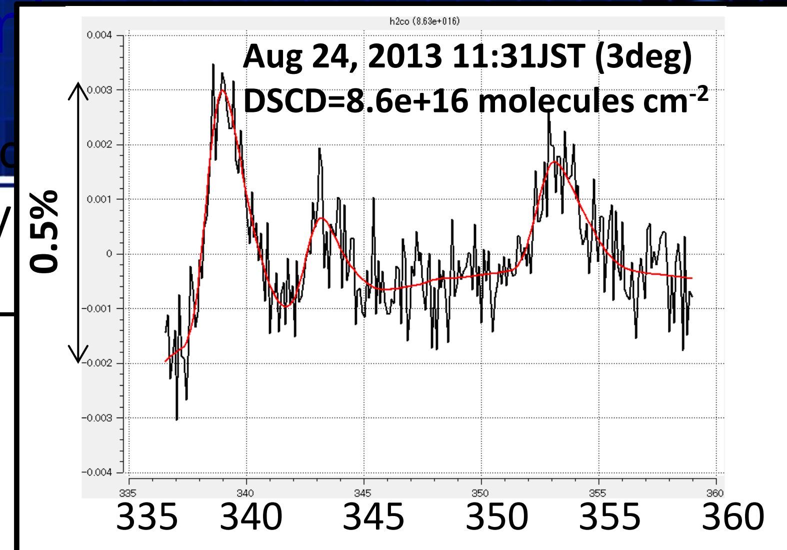
Aerosol amounts are so large that UVAI can detect BL aerosols

TEMPO hourly NO_2 sweep



HCHO and atmospheric chem

- Intermediate species of VOC oxidation, produc
- Affect HOx production and O_3 photochemistry



HCHO

CH_4 oxidation (60%)

Isoprene etc

VOCs

VOCs, NOx

NO

OH

RO_2

Stavrakou et al. 2009

Biogenic (30%)

Pyrogenic (3%)

Urban source (7%)

* Quantify HCHO from ground-based observations to identify important sources and to evaluate satellite obs

TEMPO baseline products

TEMPO has a minimally-redundant measurement set for air quality.

Near-real time products will allow for pollution alerts, chemical weather, app-based local air quality.

Revised PLRA has O_3, NO_2, H_2CO as baseline

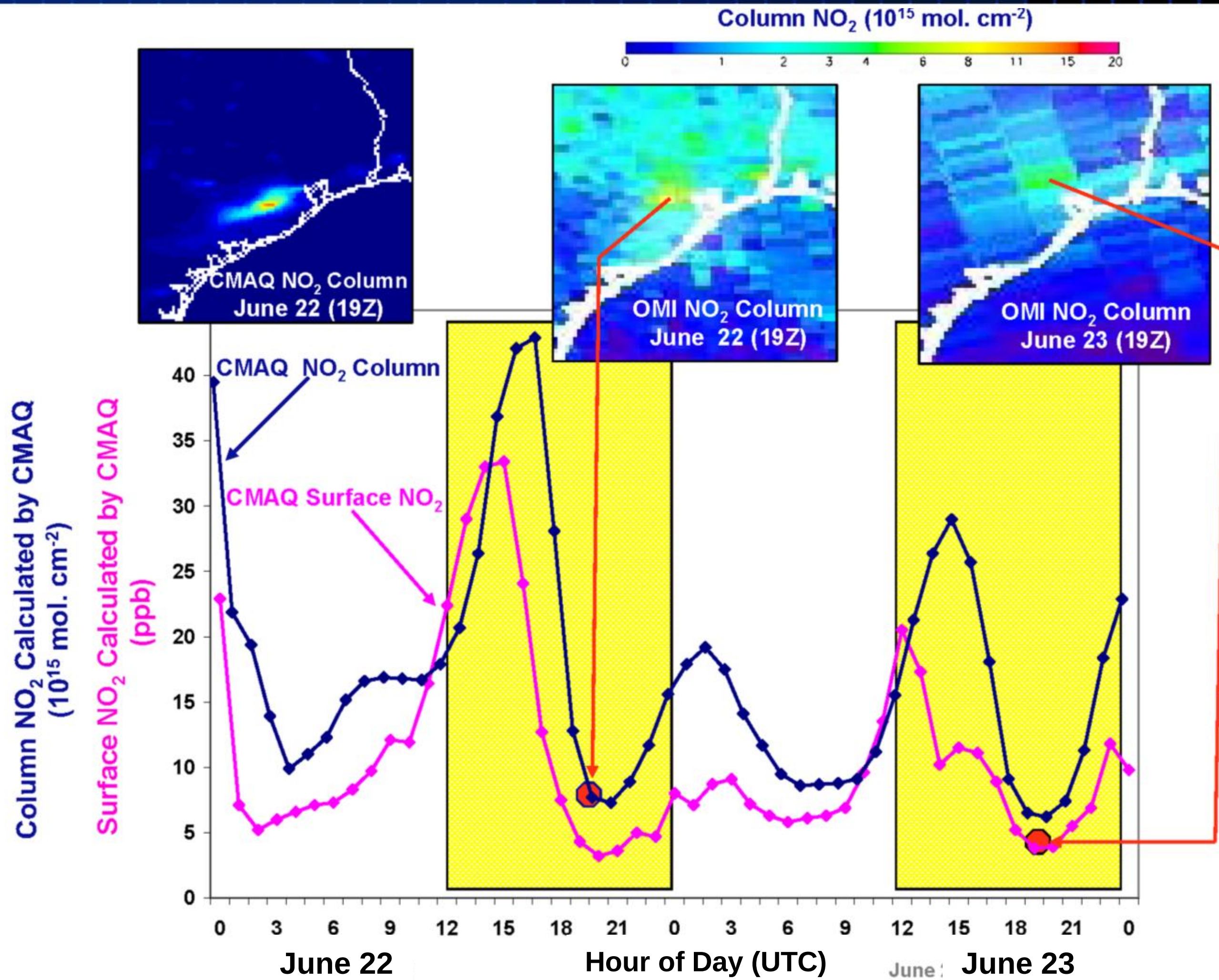
Species/Products		Typical value[2]	Required Precision	Expected Precision[3]	
				Worst	Nominal
O_3 Profile	0-2 km (ppb)	40	10	9.15	9.00
	FT (ppb) [4]	50	10	5.03	4.95
	SOC [4]	8×10^3	5%	0.81%	0.76%
Total O_3		9×10^3	3%	1.54%	1.47%
NO_2*		6	1.00	0.65	0.45
H_2CO* (3/day)		10	10.0	2.30	1.95
SO_2* (3/day)		10	10.0	8.54	5.70
$C_2H_2O_2$* (3/day)		0.2	0.40	0.23	0.17
AOD		0.1 – 1	0.05	0.041	0.034
AAOD		0 – 0.05	0.03	0.025	0.020
Aerosol Index (AI)		-1 – +5	0.2	0.16	0.13
CF [4]		0 - 1	0.05	0.015	0.011
CTP (hPa) [4]		200–900	100	85.0	60.0

[1] Spatial Resolution: 8×4.5 km^2 at the center of the domain. Time resolution: Hourly, unless noted.
[2] Typical values. Units are 10^{15} molecules•cm^{-2} for gases and unitless for aerosols/clouds, unless specified.
[3] Expected precision is viewing condition dependent; results for worst and nominal cases.
[4] FT, free troposphere: 2 km-tropopause, SOC: stratospheric O_3 column, CF: cloud fraction, CTP: cloud top pressure.
* = background value. Pollution is higher, and in starred constituents, the precision is applied to polluted cases.

Threshold products at 8×9km^2 at 80 min. time resolution.

Why geostationary? High temporal and spatial resolution

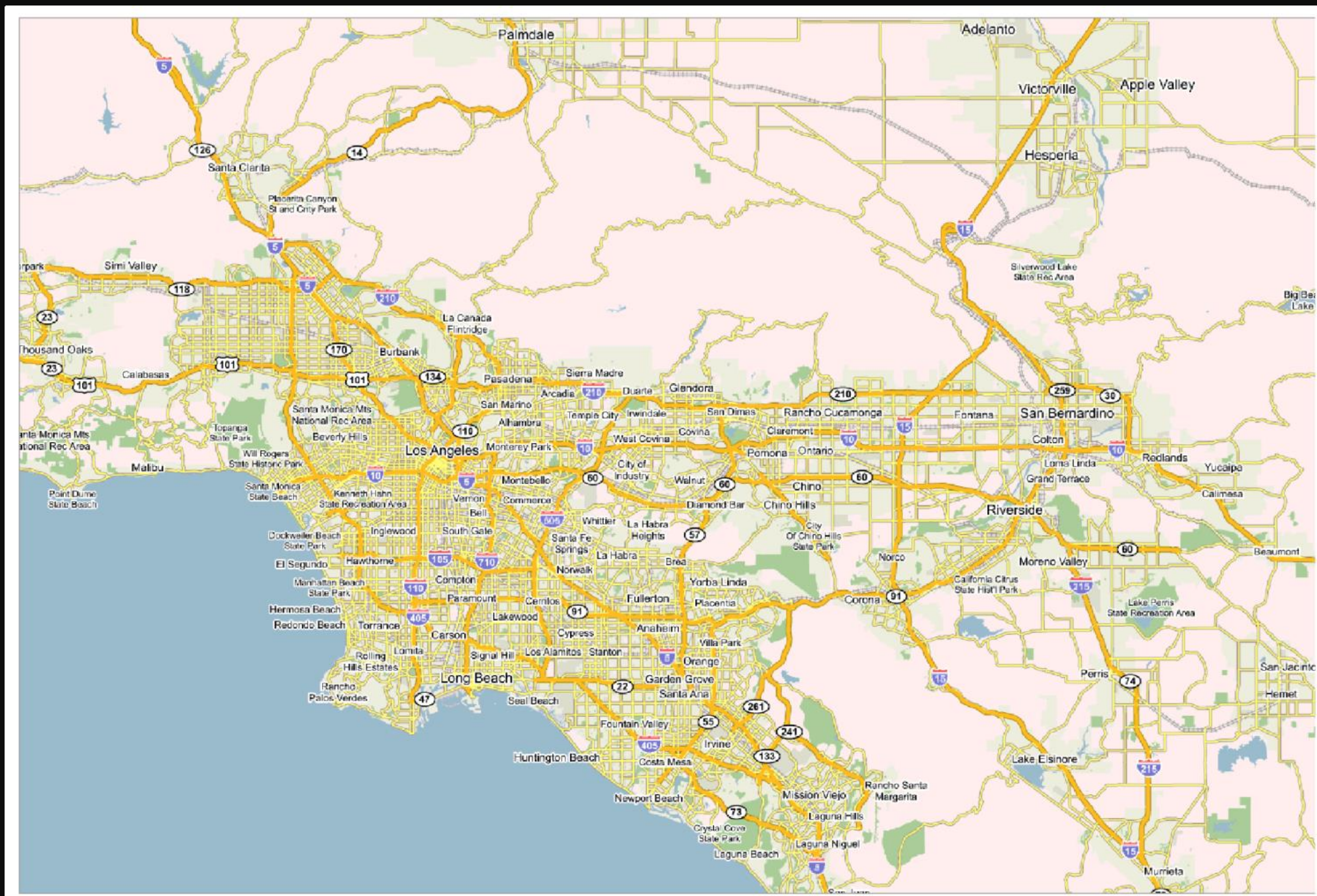
Hourly NO_2 surface concentration and integrated column calculated by CMAQ air quality model: Houston, TX, June 22-23, 2005



LEO observations provide limited information on <u>rapidly varying</u> emissions, chemistry, & transport

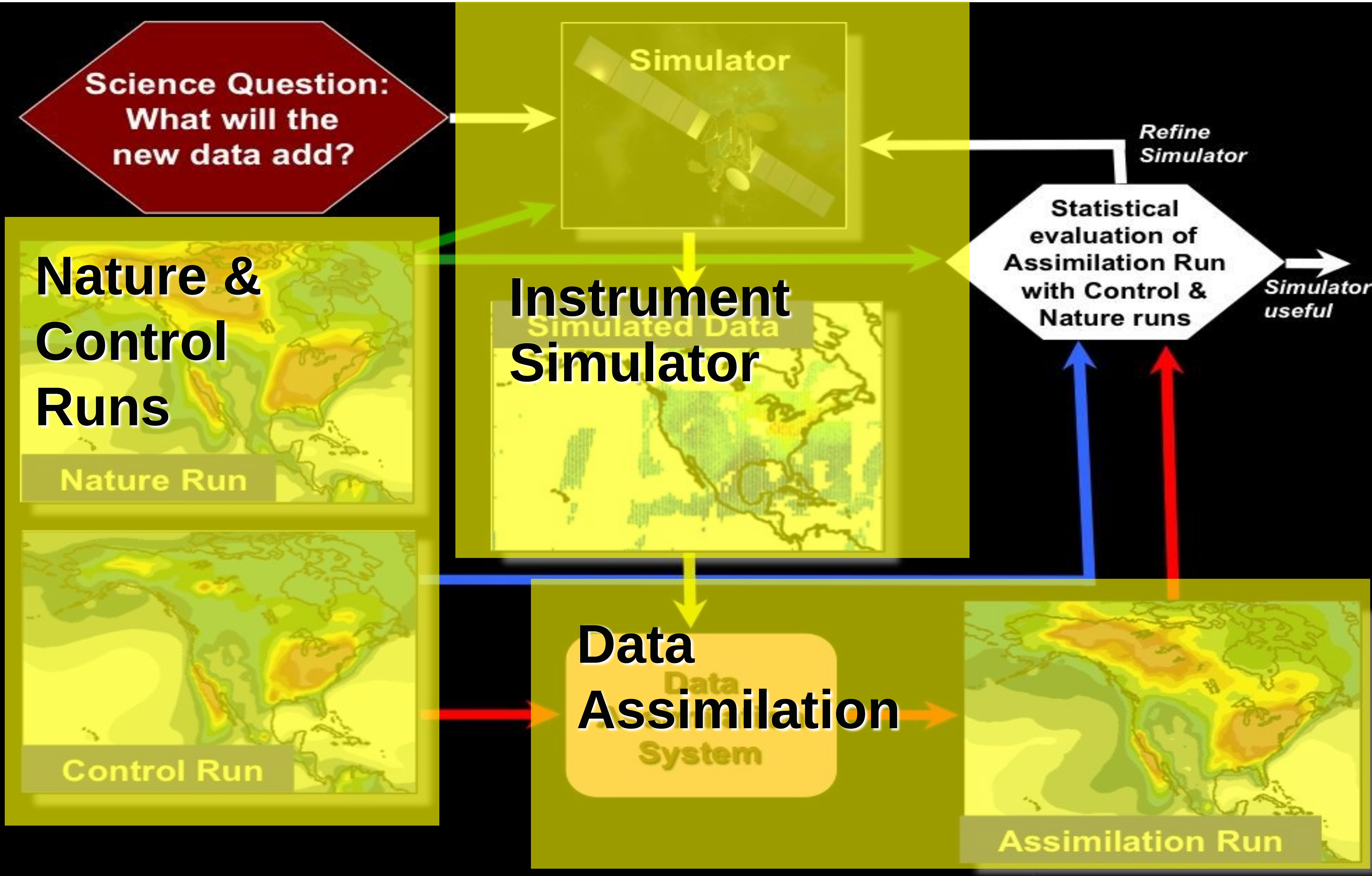
GEO will provide observations at temporal and spatial scales highly relevant to air quality processes

NO_2 over Los Angeles



Courtesy T. Kurosu

A Chemical OSSE Framework



TOLNet

Tropospheric Ozone LIDAR Network

Tropospheric Ozone Lidar Network

Objectives

- Provide high-resolution, time-height measurements of ozone and aerosols from near-surface to upper troposphere for air-quality/photochemical model improvement and satellite retrieval validation.

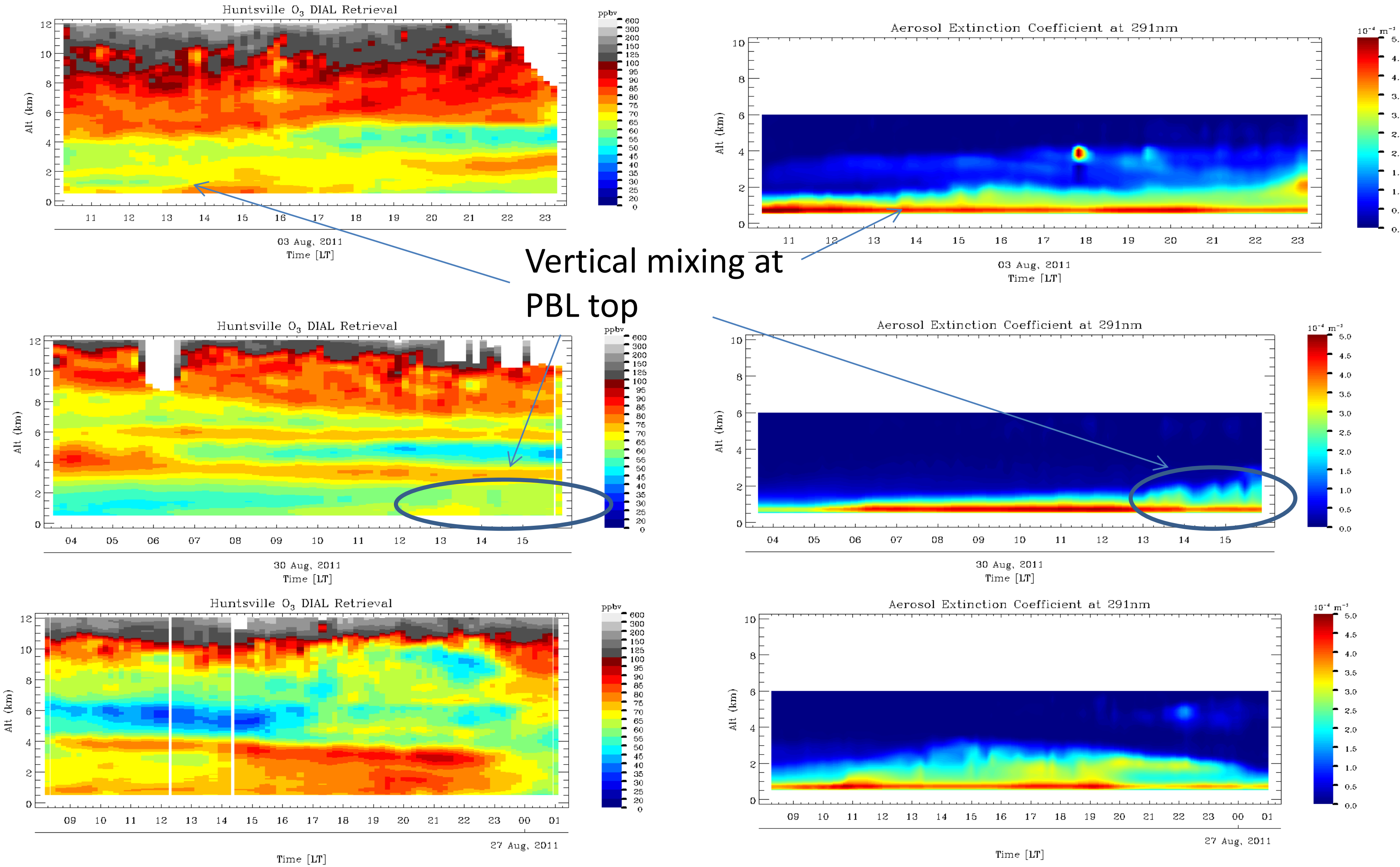
- Exploit synergies with EV-1 DISCOVER-AQ, EV-I TEMPO, GEO-CAPE, and existing networks to advance understanding of processes controlling regional air quality and chemistry.

- Develop recommendations for lowering the cost and improving the robustness of lidar systems to better enable their capability for addressing the needs of NASA, NOAA, EPA, and State/local AQ agencies.

http://www-air.larc.nasa.gov/missions/TOLNet/

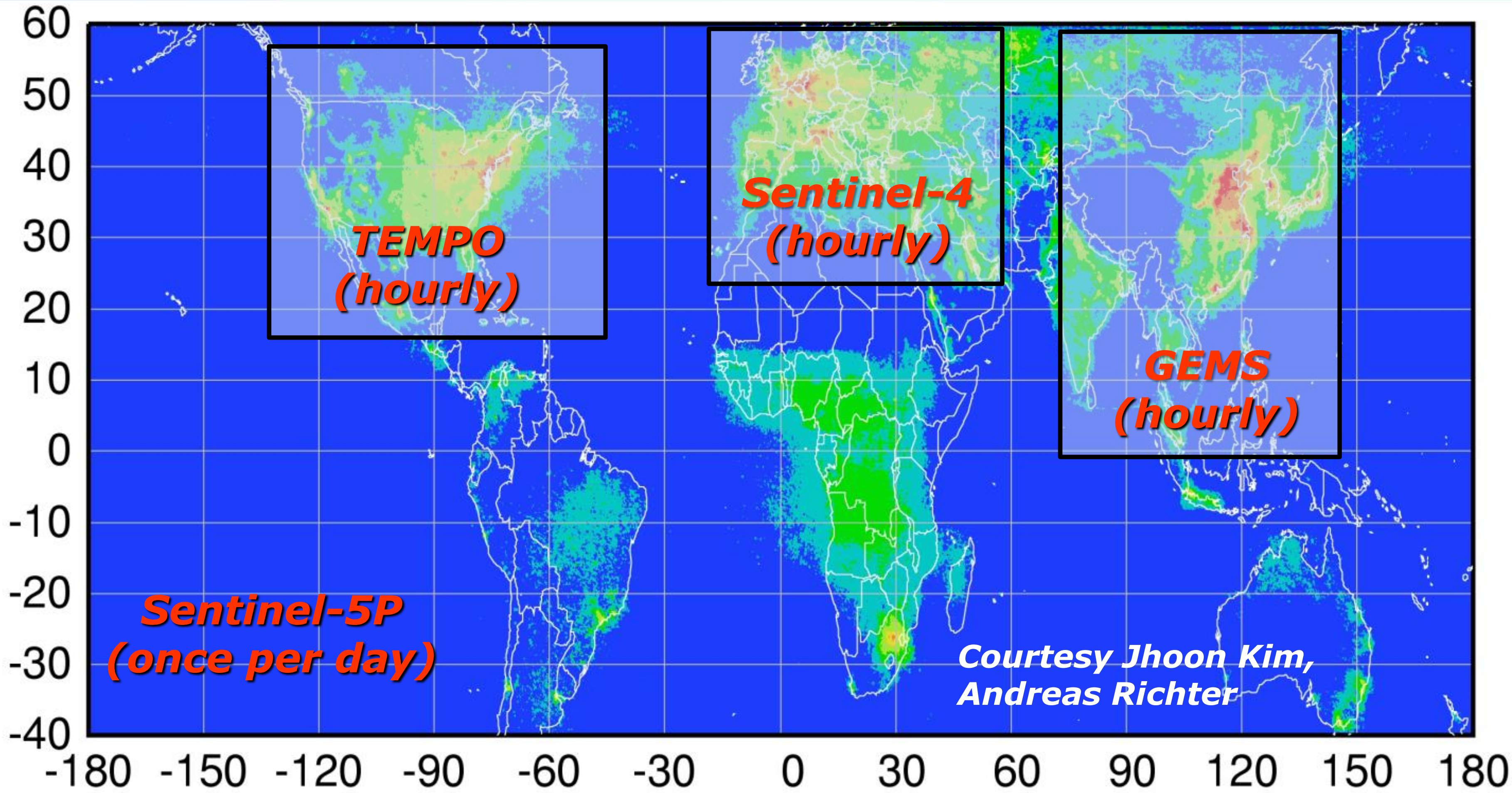
TOLNet

Tropospheric Ozone LIDAR Network



Huntsville DIAL retrieval provided by Dr. Shi Kuang, University of Alabama in Huntsville

Global pollution monitoring constellation (2018-2020)



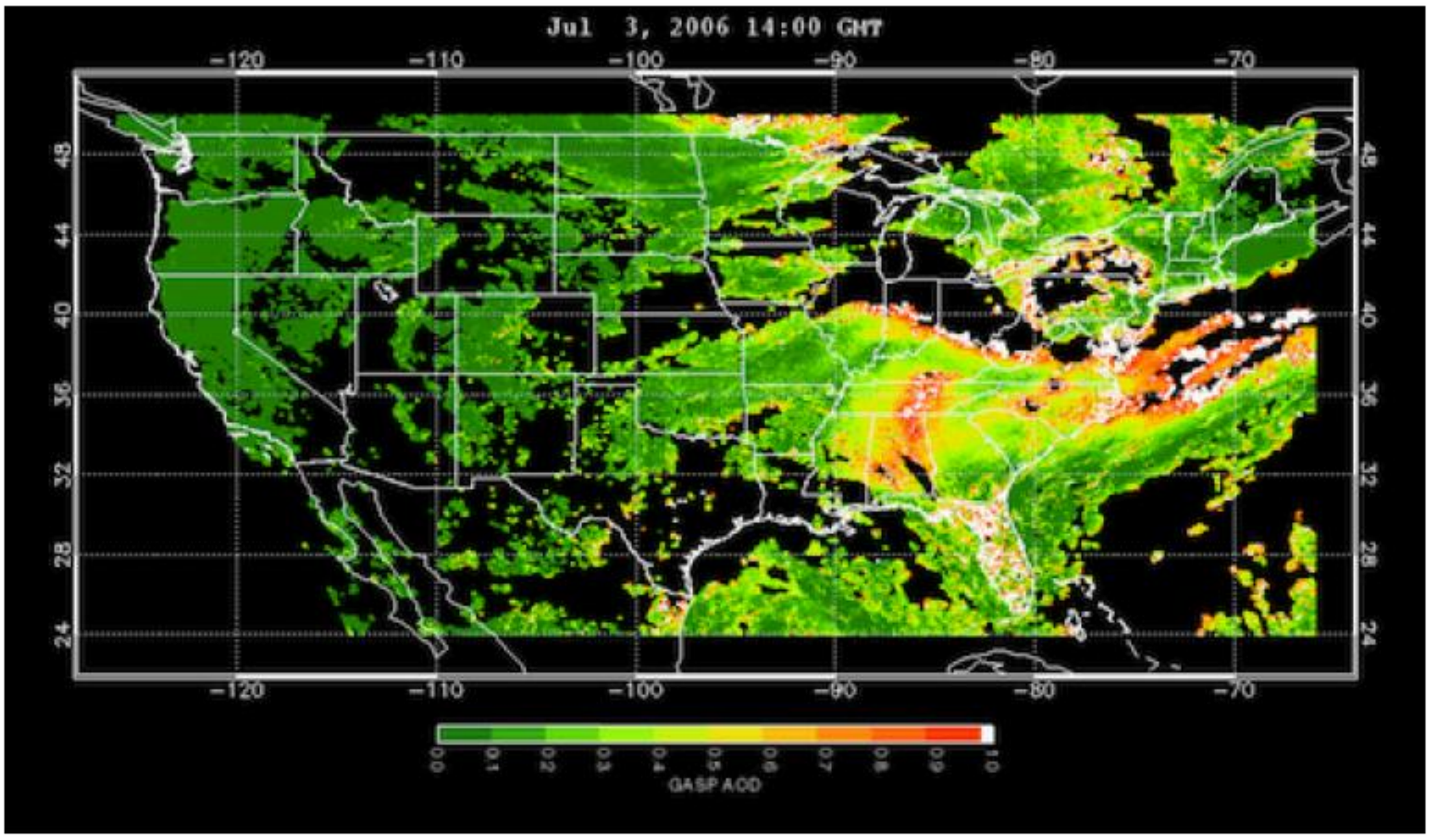
Policy-relevant science and environmental services enabled by common observations

- Improved emissions, at common confidence levels, over industrialized Northern Hemisphere
- Improved air quality forecasts and assimilation systems
- Improved assessment, e.g., observations to support United Nations Convention on Long Range Transboundary Air Pollution

TEMPO

www.epa.gov/rsig

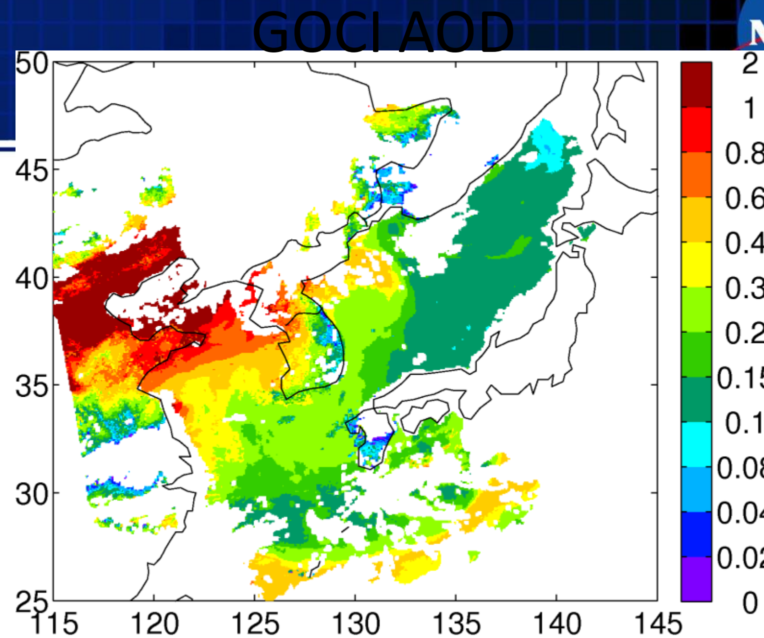
TEMPO will use the EPA's Remote Sensing Information Gateway (RSIG) for subsetting, visualization, and product distribution – *to make TEMPO YOUR instrument*



Will Geostationary Observations of Atmosphere Constituent Species Improve Air Quality Predictions?

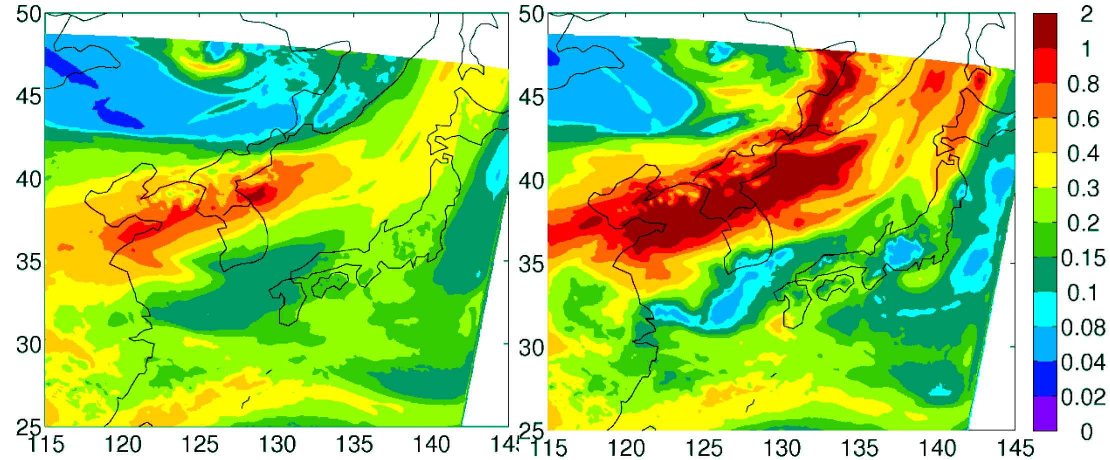
Pablo Saide & **Greg Carmichael** (University of Iowa), Jhoon Kim & Myungje Choi (Yonsei University), Chul H. Song (Gwangju Inst. Sci. & Tech.), and Yafang Cheng (MPI)

Assimilation experiments



Aug 27-29, 2012

- **Objectives:** Assess performance of assimilating GOCI AOD into a system already assimilating MODIS AOD
- **System:** WRF-Chem - GSI for MOSAIC sectional aerosol model (Saide et al., ACP 2013) allows assimilation of multiple data
- GSI AOD assimilation every 3 hours, MODIS only, MODIS+GOCI. (*Only over-sea AOD used)*



WRF-Chem
NO Assim

WRF-Chem
MODIS+GOCI Assim

Summary

- Assimilating next generation geostationary aerosol optical depth retrievals can improve air quality predictions, **BUT….**
- **Next steps –**

  - evaluate the impact of assimilation of surface PM; overland AOD retrievals; multiple wavelength AOD;

  - apply our new techniques to test the impact of Geo observations on emission estimates; &

  - use Geo observations in 4dVar coupled WRF-Chem assimilation system.

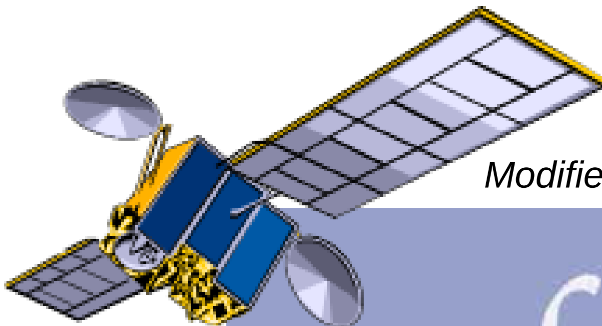
Working with Song *et al.* to implement in Korea AQ forecasting.

KORUS – AQ would be a great opportunity to make progress towards advancing our capabilities to maximize the impact on air quality prediction.

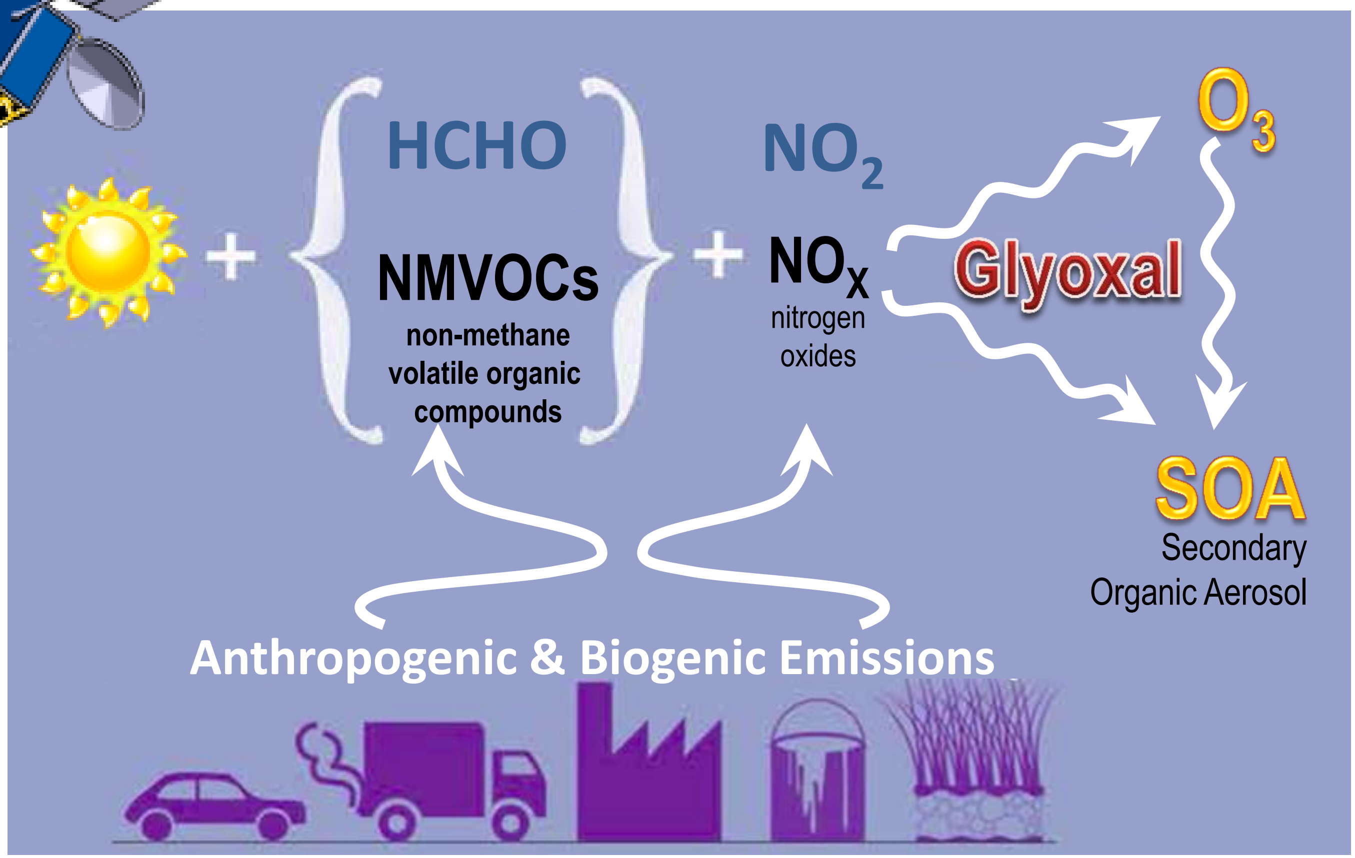
Additional observational constraints on atmospheric chemical processes: glyoxal (CHOCHO) from ground, air & space-borne measurements

Kyung-Eun Min (kyung-eun.min@noaa.gov)
NOAA ESRL CSD/ CU Boulder CIRES

Atmospheric chemical processes



Modified from Climate and Clean Air Coalition (CCAC) web page

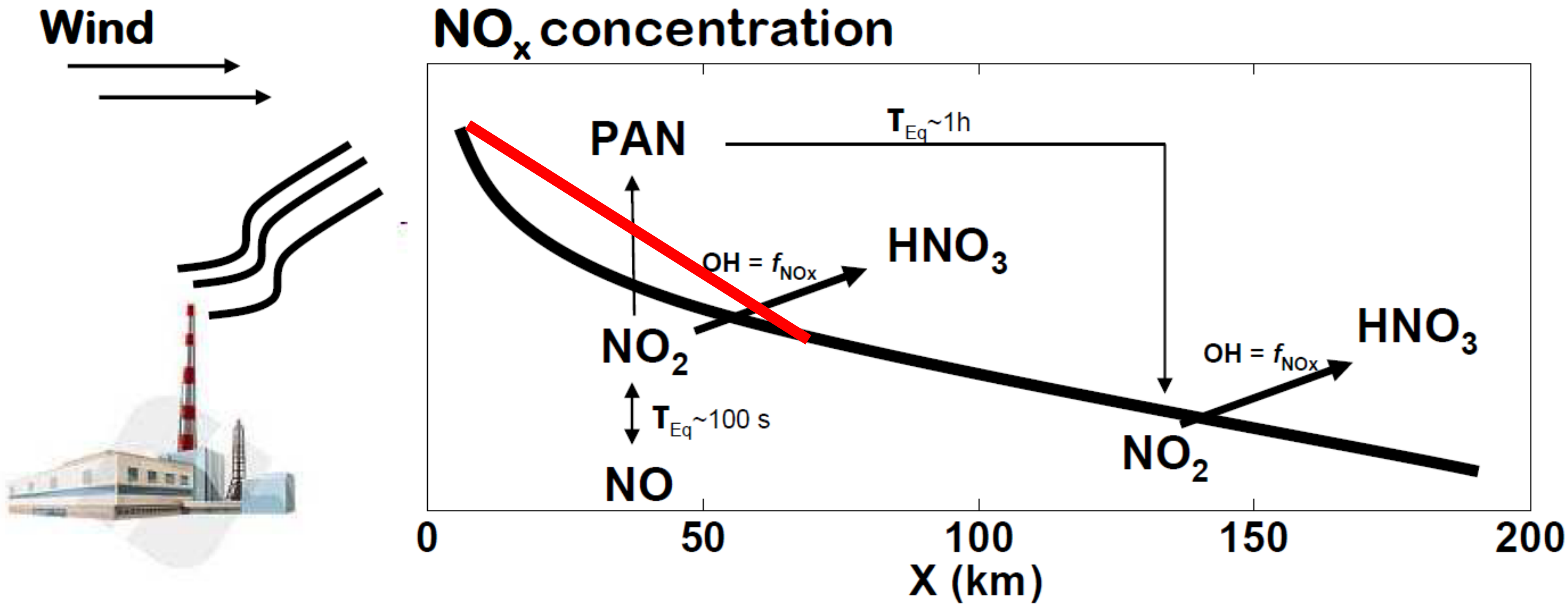


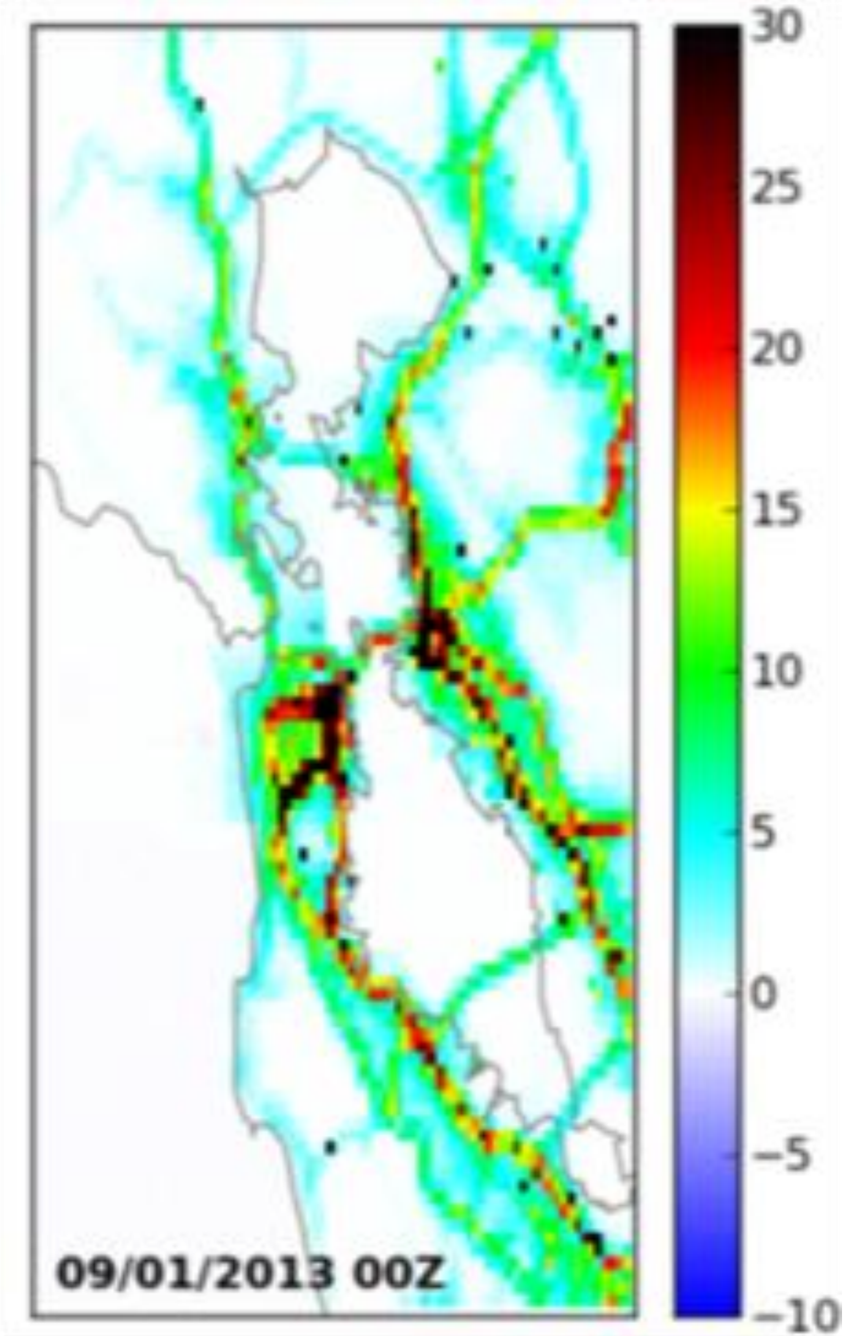
Emissions, Chemistry and NO_2 Retrievals

Ronald C. Cohen
Prof. UC Berkeley

$NASA

Science questions demand high spatial resolution





Emissions in San Francisco bay area at 1km resolution

TEMPO summary

- **Currently on-schedule and on-budget**
  - **Passed System Requirements Review and Mission Definition Review in November 2013**
  - **Passed KDP-B April 2014, now in Phase B**
  - **Most technical issues solved at the preliminary design level, following technical interchange meeting at Ball, April 2014**
  - **Passed PDR on July 31, 2014**
  - **KDP-C scheduled for November, 2014**
  - **Detectors in-house, grating and optical bench ordered**
  - **Ground systems development at SAO on schedule**
- **Satellite host selection and Instrument CDR summer 2015**
  - **TEMPO operating longitude and launch date are not known until after host selection**
- **Instrument delivery 05/2017 for launch 11/2018 or later**

TEMPO

The end!